

# Physics Opportunities with an Intense Proton Source

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- The current Fermilab program
- Long-baseline neutrino prospects
- Counting protons (dumb version)
- Other programs/benefits

# Draft 2005-8 Fermilab Accelerator Experiments Schedule

Revised Annually - This Version from June, 2003

Year		2005	2006	2007	2008
Tevatron Collider				BTeV	BTeV
		CDF & Dzero		CDF & Dzero	CDF & D0
Neutrino Program	B	OPEN	OPEN	OPEN	OPEN
	MI	MINOS	MINOS	MINOS	MINOS
Meson 120	MT	Test Beam		Test Beam	TestBeam
	MC	OPEN	OPEN	OPEN	E906
	ME/P	OPEN	OPEN	OPEN	OKM

# Draft 2009-12 Fermilab Accelerator Experiments Schedule

Revised Annually - This Version from June, 2003

Year		2009	2010	2011	2012
Tevatron Collider		BTeV	BTeV	BTeV	OPEN
			OPEN	OPEN	OPEN
Neutrino Program	B		OPEN	OPEN	OPEN
	MI		OPEN	OPEN	OPEN
Meson 120	MT	Test Beam	Test Beam	Test Beam	TestBeam
	MC	E906-DrellYan	E906-DrellYan	OPEN	OPEN
	ME/P	CKM	CKM	CKM	OPEN

- RUN or DATA
- STARTUP/COMMISSIONING
- INSTALLATION
- M&D (SHUTDOWN)

Some facts:

- Lots of exciting physics coming!
- ~2008: highest energy goes to LHC
- ~2005: Fermilab becomes **the place where neutrino oscillation results come from**

Compelling case for exploiting and extending  
the Fermilab neutrino program

- Exciting physics to explore
- Utilize elements in place
- Utilize local expertise

# VERY brief overview of neutrino situation

## References:

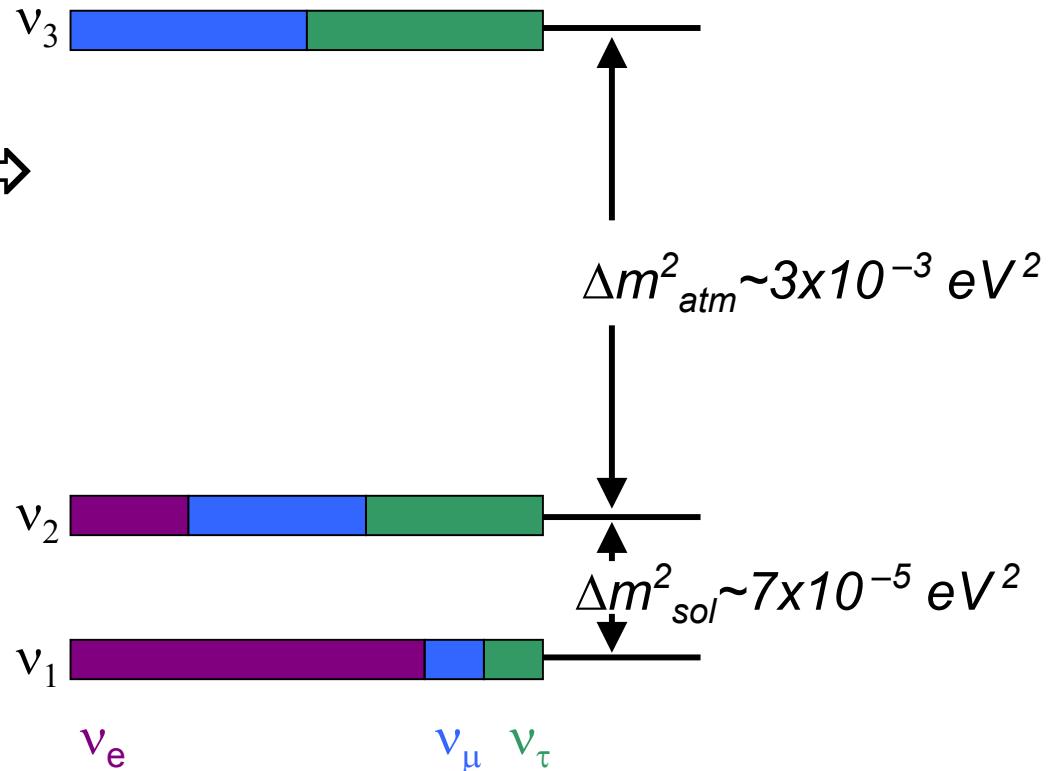
- Stephen Parke at “Physics Landscapes” Open Session 9/16
- Upcoming “Neutrino” Open Session **11/7**

Evidence	Effect real?	Is it osc?	$\Delta m^2$ (eV <sup>2</sup> )	Flavor
Solar: Homestake missing $\nu_e$	Gallex, SAGE, K, Super-K  SNO, (KamLAND)	SNO	$7 \times 10^{-5}$ (MSW)	$\nu_e \rightarrow \nu_\mu, \nu_\tau$ $< 13\% \nu_s$  $(\bar{\nu}_e \rightarrow ?)$
Atmospheric: Kamiokande missing $\nu_\mu$	Super-K, (K2K)	(Super-K)	$3 \times 10^{-3}$	$\nu_\mu \rightarrow \nu_\tau$ $< 20\% \nu_e$ $< 25\% \nu_s$
LSND: accelerator $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$		appear- ance	0.3-1	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

Solar + atmospheric  $\Rightarrow$   
a consistent picture

$\square \theta_{12} \sim \pi/6, \theta_{23} \sim \pi/4, \theta_{13} < 0.2$

$\square \delta = ???$



$$U = \begin{matrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{matrix} \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

with  $c_{ij} \equiv \cos \theta_{ij}$        $s_{ij} \equiv \sin \theta_{ij}$

# LSND and the curse of arithmetic

$$\Delta m^2_{LSND} \sim 1 \quad \Delta m^2_{sol} \sim 7 \times 10^{-5} \quad \Delta m^2_{atm} \sim 3 \times 10^{-3}$$

but  $\Delta m^2_{31} = \Delta m^2_{21} + \Delta m^2_{32}$

and Z lineshape  $\Rightarrow N_\nu = 2.994 \pm 0.012$

Conclusion:

If LSND is correct, it requires something drastic

From the current round --

- MiniBooNE, Minos, K2K
- more from Super-K, SNO, Kamland...

we will have:

LSND: yes or no

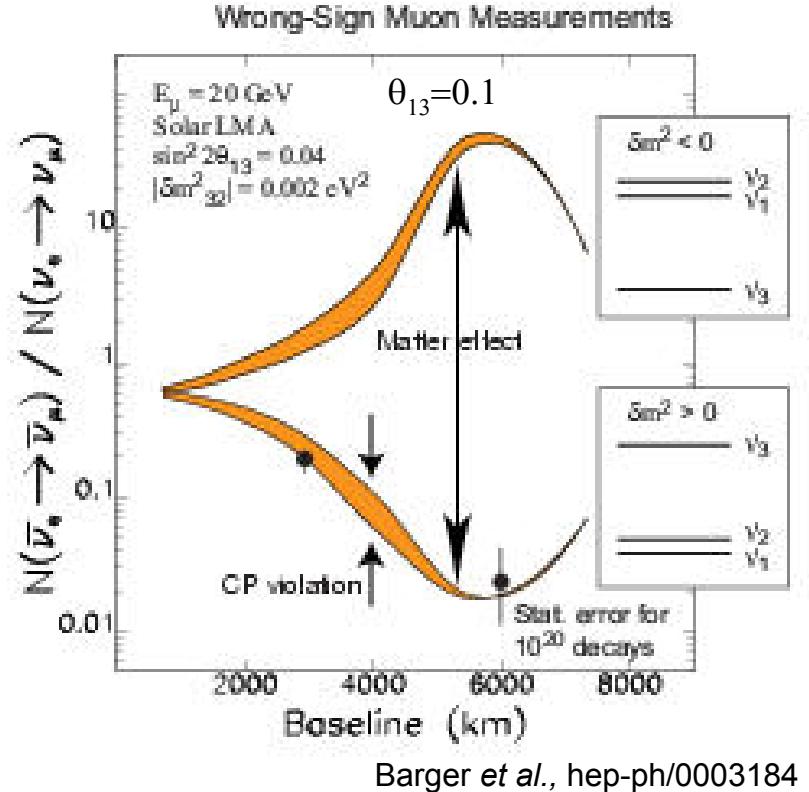
- New physics!
- Short baseline stays interesting
- Plus all this (with different meaning)

- $\Delta m^2_{\text{atm}}$ ,  $\Delta m^2_{\text{sol}}$  well measured
- $\theta_{12}$ ,  $\theta_{23}$  pretty well known
- Know if  $\theta_{13} \gtrsim 0.1$  or not

# The next goals:

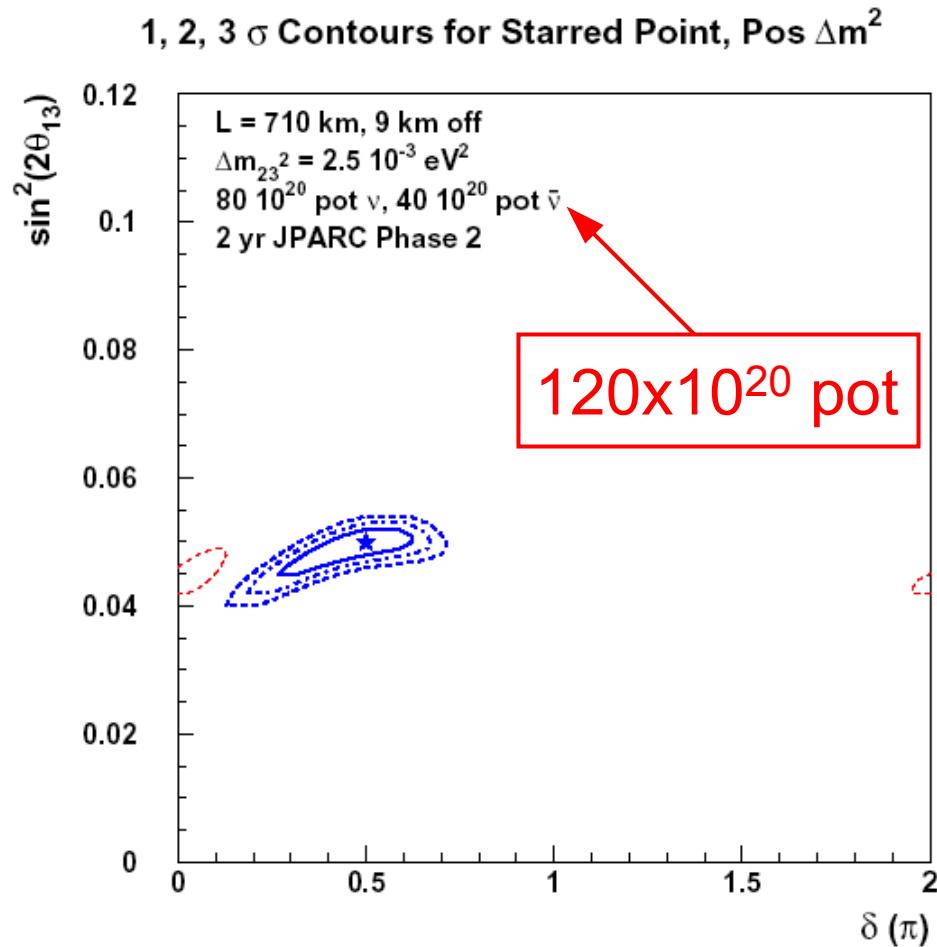
- Further confirming the picture (cf. CKM)
- Ordering the mass hierarchy
- CP violation

This is **hard**:



$$P(\nu_e \rightarrow \nu_\mu) - P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu) = 16 s_{12} c_{12} \underline{s_{13}} c_{13}^2 s_{23} c_{23} \times \\ \underline{\sin \delta} \sin \left( \frac{\Delta m_{12}^2 L}{4E} \right) \sin \left( \frac{\Delta m_{13}^2 L}{4E} \right) \sin \left( \frac{\Delta m_{23}^2 L}{4E} \right)$$

# NuMI 4 yr $\nu$ , 2 yr $\bar{\nu}$ , Proton Driver and JPARC, Phase 2



Hierarchy finally resolvable at > 95% CL with 6 yrs of proton driver.

(real story in next talk...)

Era	Program	Need ( $10^{20}$ p.o.t./yr)		Available ( $10^{20}/\text{yr}$ )	
		Booster	MI	Booster	MI
Current	Run II	0.5	0.5		
	MBooNE	$\frac{5}{5.5}$	$\frac{0.5}{}$	$2.7 \rightarrow 5.5$	0.5
Near-term ~2005	Run II	0.5	0.5		
	Minos	2.5	2.5		
	MBooNE?	$\frac{5}{8.0}$	$\frac{3.0}{}$	$5.5 \rightarrow 7.6$	3.2
Mid-term ~2008	Run II	0.5	0.5		
	Minos	4	4		
	BooNE?	$\frac{5}{9.5}$	$\frac{4.5}{}$		
Long-term ~2010	Off-axis (BTeV,CKM)	20	<b>20</b>		

$$\frac{20 \times 10^{20} \text{ pot/yr} \times 120 \times 10^9 \text{ eV} \times 1.6 \times 10^{-19} \text{ J/eV}}{2 \times 10^7 \text{ s/yr}} =$$

1.9 MW

Note: requires  $> 1.9 \times (8/120) = 0.13 \text{ MW}$  at 8 GeV

Current Booster:  $\sim 0.02 \text{ MW}$  ( $\rightarrow 0.04?$   $\rightarrow 0.05?$ )

Proton Driver: 0.5-2 MW at 8 GeV

## Fermilab: in...or out?

J-PARC → Kamioka (2009)

- 295 km baseline -- matter effects small
- 0.75 MW → 4 MW

Brookhaven → Homestake/WIPP (????)

- 2500-2900 km baseline
- 1 MW

Proton Driver could support a  
broad physics program of its own

- Two Fermilab studies
- Short-baseline neutrino oscillation
  - if MiniBooNE confirms LSND
  - multiple sterile neutrinos?
- Low-energy neutron source
  - optimize for elementary particle physics
- Low-energy muon source

Head-start for bigger projects?

- SC Linac a warm-up (cool-down?) for LC
- $\nu$  Factory R&D/source

Big questions:

- PD and various LC scenarios
- What constitutes a viable program?
- What does 2012 look like  
**without PD?**